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RESEARCH MEMORANDUM

PRELIMINARY DISCUSSION OF FUEL TEMPERATURES ATTAINED IN SUPERSONIC AIRCRAFT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INTRODUCTION

It is well known that when aircraft operate at supersonic speeds the aircraft surfaces become hot. It is apparent that fuels stored inside the airplanes will also become heated. The fuel temperatures that are attained depend upon the aircraft speed, the flight time, the flight altitude, the materials of construction, the location of the fuel tanks relative to the aircraft skin and hot engine parts, and on other factors.

Therefore, it is impossible to predict quantitatively the fuel temperatures that will be attained in aircraft without detailed design information on each machine.

DISCUSSION

The present report is of a preliminary nature, as the title indicates, and it has not had an editorial review nor have the data been checked. The NACA has made some calculations on the basis of information available in order to indicate the general fuel temperature range to be encountered. Some of this information is shown in the following figures.

Figure 1 shows a possibility for a flight plan of a future supersonic interceptor airplane. This airplane would have all of the fuel carried in uninsulated fuselage tanks. It was impossible to estimate what the heat transfer would be from the engine and afterburner; therefore it was assumed that the fuel was not heated from this source.

The figure shows a plot of altitude against flight time in minutes, and it also shows the fuel temperature attained during the 35-minute flight. The numbers under the curve represent flight Mach numbers. The airplane would fly to an altitude of 25,000 feet at Mach number of 1.5, then to 35,000 feet at Mach 2.0, and to 60,000 feet at Mach 3.0. The airplane would fight at 60,000 feet for 5 minutes and then return to its base. The maximum fuel temperature, in the aircraft tanks, attained during this flight is calculated to be 200° F.

Figure 2 shows the calculated fuel temperatures attained in the tanks of another supersonic fighter. In this case, the fuel tanks under consideration are carried in the wings. The fighter is rated at Mach 2.5 at an altitude of 60,000 feet. The calculations are shown for both insulated and uninsulated tanks and for both JP-4 and JP-5 fuels. It was assumed that the tanks could be pressurized up to a maximum value of 5 pounds per square inch absolute. This pressurization would help to prevent the boil-off of the relatively volatile JP-4 fuel. However, with an uninsulated tank a very large part of the JP-4 fuel is evaporated as indicated in figure 2. Forty percent of the fuel would be lost overboard if the vaporized fuel were not burned or recovered. If the fuel were lost, the flight would be restricted to about 18 minutes instead of the flight mission of 30 minutes. The maximum temperature of JP-4 fuel under the described conditions would be about 260° F.

Shown on the same figure are the data for JP-4 fuel in an insulated tank. It was assumed that a 1/2-inch layer of cork was used as the insulation on the outside of the tank. In this case only 1 or 2 percent of the JP-4 fuel was lost because of evaporation and the maximum temperature of the JP-4 fuel was about 100° F.

For the same flight mission and tank pressurization, about 13 percent of the JP-5 fuel would be lost because of evaporation. The maximum temperature of the JP-5 fuel would be about 310° F during the 30-minute flight. The maximum temperature of the JP-5 fuel in an insulated tank would be about 140° F.

Figure 3 shows data calculated for a missile designed to fly at Mach 3.0 at an altitude of 70,000 feet for a flight time of 3 hours. Calculations were again made for both JP-4 and JP-5 fuel with insulated and uninsulated fuselage tanks. In all cases it was assumed that the fuel tanks were pressurized to 5 pounds per square inch absolute.

In the case of an uninsulated tank about 25 percent of the fuel would be evaporated in 2 hours and 15 minutes at which time all of the fuel would be used or lost by evaporation. The maximum fuel temperature in this case would be about 210° F. With an insulated tank practically none of the JP-4 fuel is lost during the 3-hour flight. The maximum JP-4 temperature with the insulated tank would be about 90° F.

The JP-5 fuel in the missile would be evaporated in an uninsulated tank to the extent of over 10 percent. It was assumed that this fuel was lost and the flight time was reduced by a corresponding amount. The JP-5 would attain a temperature of about 310° F in the uninsulated tank.

An insulated tank and pressurization of 5 pounds per square inch absolute would prevent vaporization loss of JP-5. The maximum JP-5 temperature with the insulated tank would be about 110° F.

It would appear that the insulation of aircraft fuel tanks would almost eliminate problems of elevated fuel temperature in tanks. However, it should be mentioned that some airframe manufacturers consider it to be impractical to insulate fuel tanks for supersonic aircraft. Therefore, these manufacturers are expecting fuel temperatures as high or higher than those shown in figures 2 and 3. The manufacturer of a missile for a mission similar to that of figure 3 expects a fuel temperature of 400° F as opposed to the NACA calculated temperature of 310° F. The difference is explained by the fact that the manufacturer expects heat to be rejected from the ram-jet engine to the fuel, whereas, the NACA calculations are concerned only with aerodynamic heating. This illustrates the fact that the NACA calculations are probably somewhat lower than the temperatures that will actually be encountered in flight.

In addition to elevated fuel temperatures due to aerodynamic heating, the fuel temperatures in most cases will be elevated still more because of heat absorbed in the fuel system. Table I shows fuel temperatures to be expected in a supersonic airplane. The data are representative of temperatures submitted by various engine manufacturers to the NACA. The data represent the temperatures to be expected from the fuel tank to the injection nozzle in a supersonic fighter. The mission includes take-off, climb to 65,000 feet, flight at Mach 1 at 65,000 feet, combat at Mach 2 at 35,000 feet, return to base, hold at Mach 0.4 at 15,000 feet, and land. Reading the table from left to right shows that the mission will include sea-level flight at Mach 0.9 for 10 minutes. The temperature of the fuel in the tank will be 110° F. The temperature of the fuel will be 124° F at the exit of the pump, 125° F at the exit of the fuel control, 148° F at the exit of the fuel-to-oil heat exchanger, and 153° F at the fuel injector.

The maximum fuel temperature for the airplane and flight under consideration is at the Mach 1, 65,000-foot altitude condition. The fuel temperature at the exit of the fuel-to-oil heat exchanger will be 362° F and at the injector the fuel temperature will be 400° F.

It is of interest to note that the fuel temperature at the fuel injector is much higher for the Mach 1 flight condition than for the Mach 2 condition. At the Mach 2 condition, the heat rejection from the oil to the fuel is about 3500 Btu per minute. At this maximum power condition, the fuel flow is also at a maximum so that the temperature attained by the fuel is lower than at the Mach 1 condition. In this case the heat rejection from the oil to the fuel is about 3100 Btu per minute, but the fuel flow through the heat exchanger is much lower than for the Mach 2 condition. Therefore, the fuel temperature is much higher. 3562

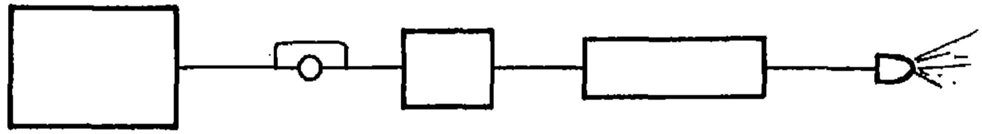
Thus it is shown that even when the fuel temperature in the tank is moderate, such as 140° F, the fuel gets much hotter as it proceeds through the engine.

CONCLUSIONS

In conclusion, it seems apparent that elevated fuel temperatures will be encountered in the fuel systems of supersonic aircraft. In order to combat this problem successfully, it will be necessary to attack it along three lines. First, the airframe manufacturer should seriously consider insulating fuel tanks wherever possible. Second, the engine designer should make every effort to minimize the heat load that is rejected to the fuel. Third, the fuel manufacturer should endeavor to make a fuel that will be thermally stable at elevated temperatures.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 11, 1955

TABLE I. - FUEL TEMPERATURES THROUGH AN ENGINE



ALTITUDE	MACH NO.	TIME, MIN	FUEL TANK, °F	PUMP, °F	CONTROL	FUEL-TO-OIL HEAT EXCHANGER	FUEL INJECTOR
SEA LEVEL	0.9	10	110	124	125	148	151
65,000	1.0	30	140	210	211	362	400
35,000	2.0	10	135	145	146	182	186
15,000	0.4	10	100	161	162	233	253

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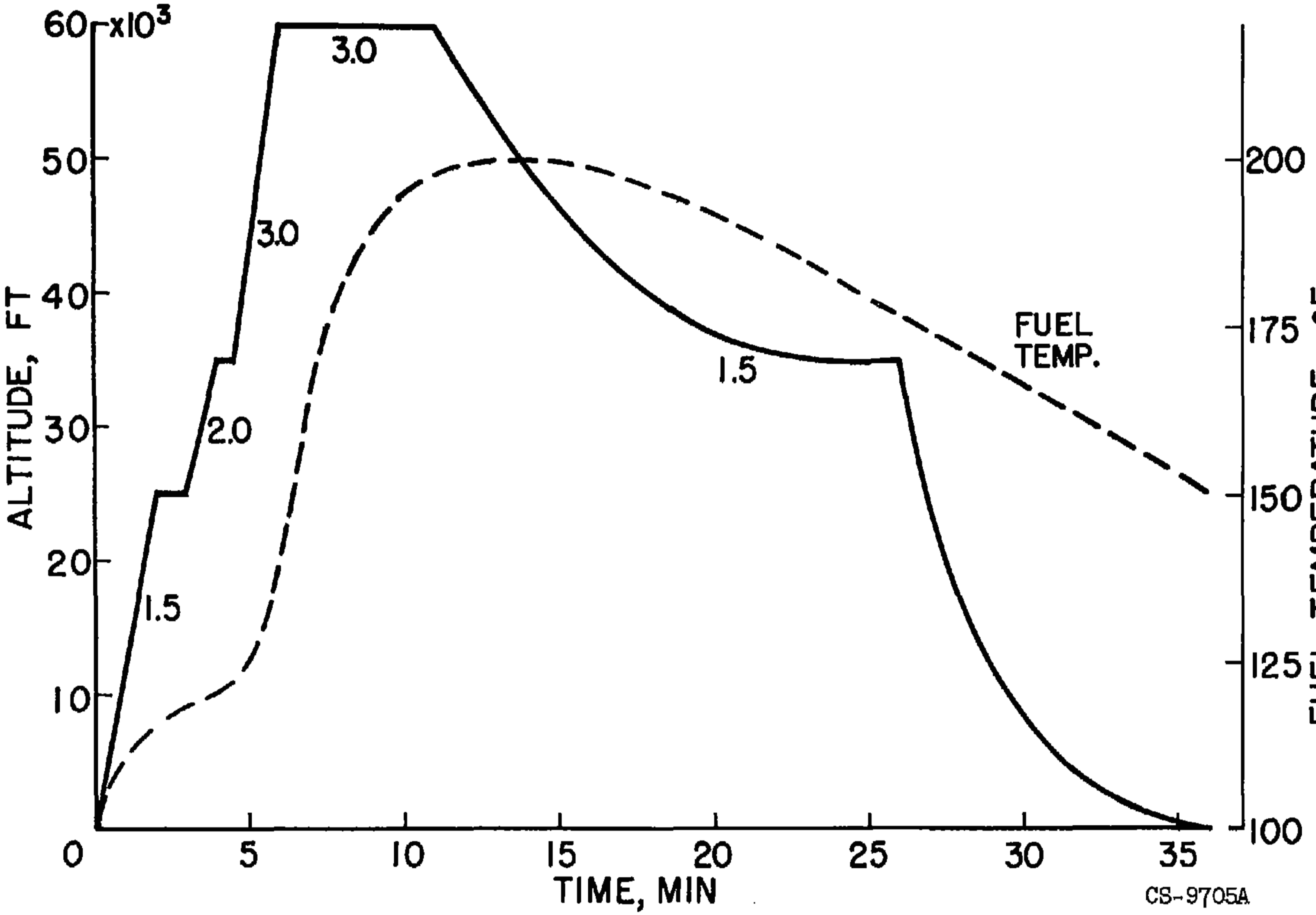

Figure 1. - Possible supersonic flight plan.

3662

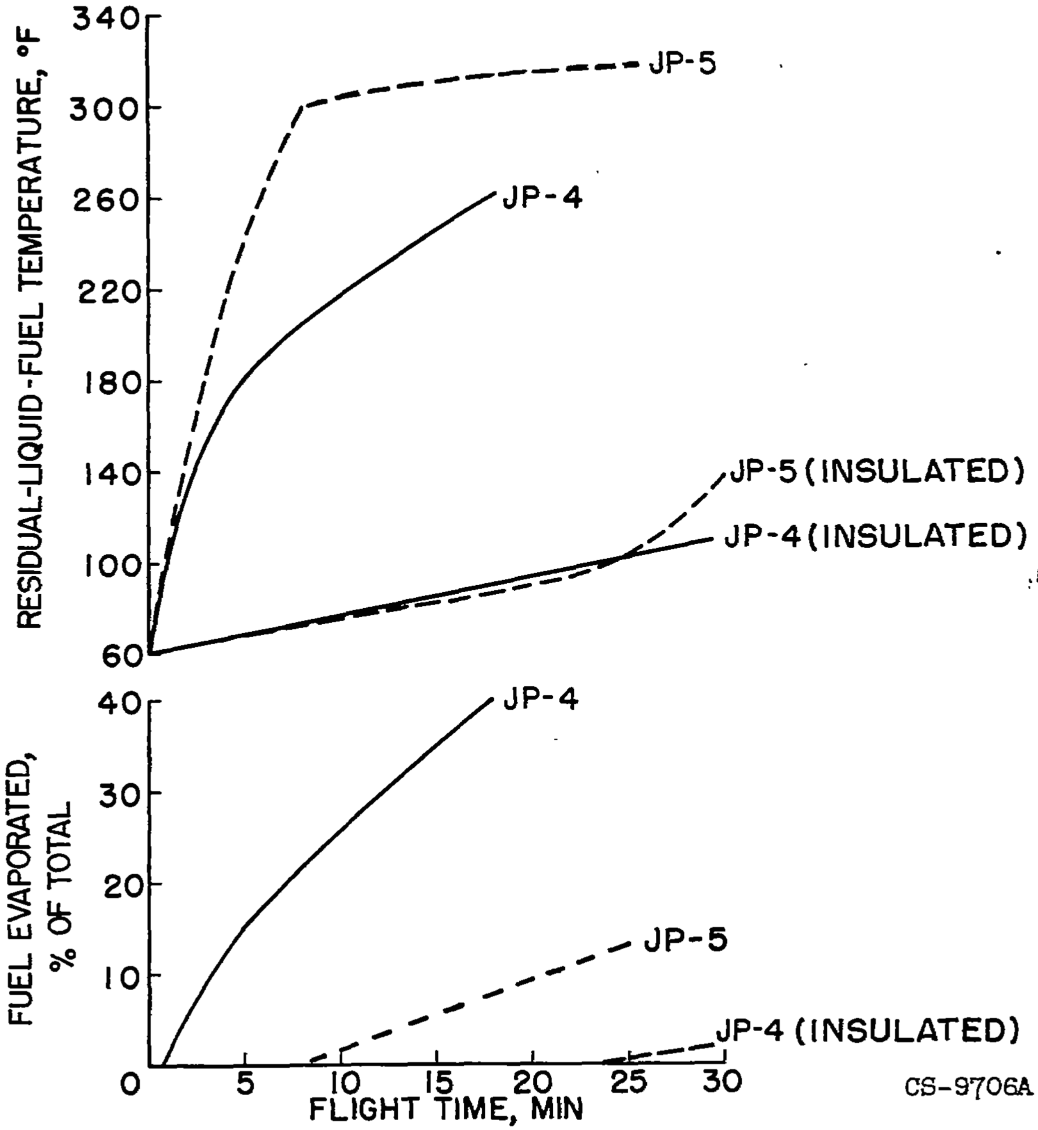

Figure 2. - Calculated fuel temperatures. Fighter; Mach number, 2.5; altitude, 60,000 feet; tank pressure, 5 pounds per square inch absolute.

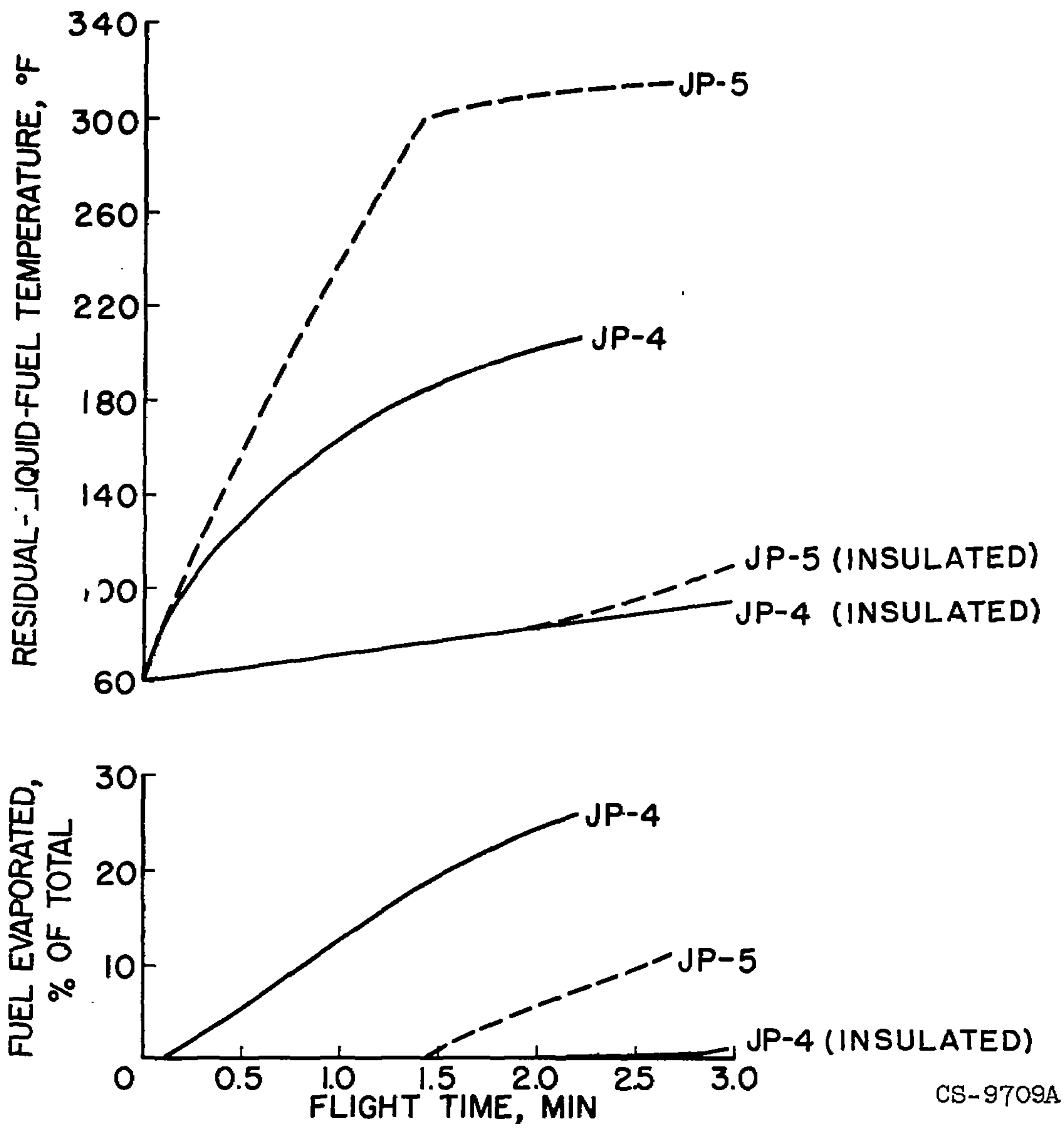

Figure 3. - Calculated fuel temperatures. Missile; Mach number, 3; altitude, 70,000 feet; tank pressure, 5 pounds per square inch absolute.

NACA-Langley - 3-15-55 - 350